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High Contrast PDLC Panels Having a Matrix in Which Pole Directions are Randomly Distributed in a Plane

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ABSTRACT

A new structure of a PDLC panel has been developed. In the PDLC panel, liquid crystal molecules tend to be oriented parallel to the substrate surface and random in the substrate plane, and effective refractive anisotropy Δn of the liquid crystal becomes larger. In this paper, relationship between deformation and optical property is reported.

INTRODUCTION

A Polymer Dispersed Liquid Crystal (PDLC) display was proposed for many uses such as a light valve for a projector and a reflective display[1,2], because it dose not need any polarizer.

There are some kind of PDLC panels having matrix structure in which liquid crystal is dispersed in polymer. For example, NCAP (Nematic Curvilinear Aligned Phase) are well known as PDLC in which nematic droplets are perfectly surrounded by polymer and isolated from each other. PNLCD (Polymer Network Liquid Crystal Display) has matrix structure in which the liquid crystal is dispersed continuously in three dimensional polymer network.

In the PDLC panels, there were some techniques to increase contrast ratio. One of the technique is to increase the scattering strength. To increase the scattering strength, it is important to optimize the matrix size, the panel thickness, and the refractive anisotropy (Δn). [3]

Usually liquid crystal molecules are three dimensionally random in PDLC panels (Fig.1(a)). Their perpendicular component of Δn to substrate surface is not effective for scattering. If the liquid crystal molecules are aligned more parallel to the substrate surface, parallel component of Δn increases. Fig.1(b) shows molecular alignment structure in which the molecules tend to be oriented parallel to the substrate surface and random in the plane of the substrate. If liquid crystal molecules are oriented in one direction in the plane, mismatch of the refractive index in the liquid crystal matrix decreases, and the scattering strength decrease. To maximize the scattering strength, the liquid crystal molecules must be oriented randomly in the plane of the substrate. In this structure the contrast ratio becomes higher.

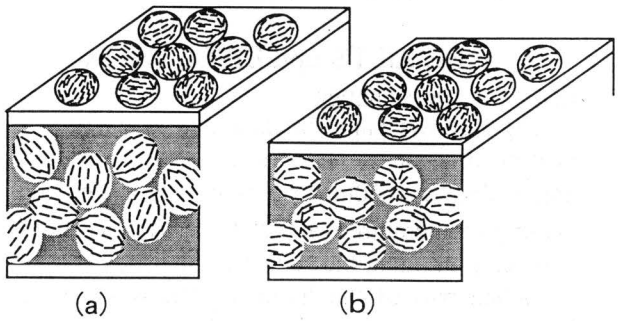

Fig.1 Schematic views of this study. Fig.1(a) shows a usual PDLC panel. Fig.1(b) shows a PDLC panel in which poll direction of the matrix is oriented parallel to the substrate.

EXPERIMENTAL

Sample preparation

To realize this structure, the following new method, High Temperature Press Method, was used. First, the PDLC panels were made by a photo-polymerization phase separation technique under the condition that the panels were unsealed. In this experiment, liquid crystal ratio in the matrix is set to be 75% in weight. The panels were pressed and kept at isotropic temperature. At the isotropic temperature, viscosity of the liquid crystal was quite low and cubic volume was increased, and followed by running out of the excess liquid crystal from the unsealed portion. After that, the panels were cooled down to the room temperature. Thus panel gap became thinner.

At this time, the matrix structure was deformed into compressed structure and pole directions in the

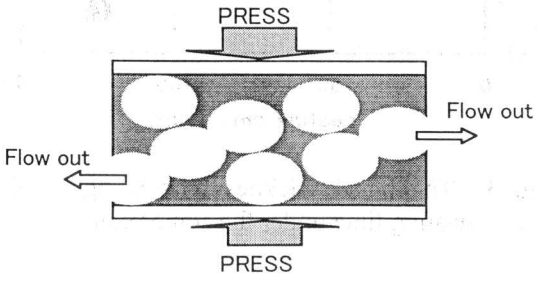

Fig.2 Conceptual diagram of the high temperature press method. The PDLC panels were pressed under the isotropic temperature, and a part of liquid crystal flowed out.

matrix were oriented parallel to the substrate surface. In this structure, the liquid crystal molecules tend to orient parallel to the substrate surface(Fig.1(b)). Though the liquid crystal is drawn with the droplet structure in the figure, actually it is considered being PNLCD structure, in which the liquid crystal portion are continued three dimensionally each other, because the liquid crystal flowed out.

RESULTS and DISCUSSION

Panel thickness change

Fig.3 shows panel thickness as a function of the heating time on some samples. In this case, the panel size was 30mm×30mm×12.3 μ m, and the heating temperature was 120℃. The measurements were carried out at the center of the panels.

When part of the liquid crystal was flowed out from the unsealed portion, and the matrix structure was deformed into a compressed structure, the deformation rate P was defined by a following equation .

$$P = 1 - \frac{d_{after}}{d_{before}}$$

where d_{after} is a thickness after deformation and d_{before} is a thickness before deformation.

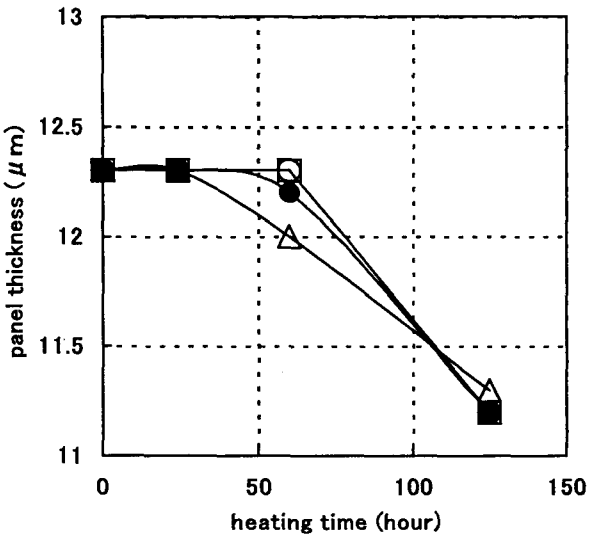

Fig. 3 The panel thickness depending on the heating time under the compression.

Transmittance curve

Fig.4 shows a transmittance curve at scattering states of the PDLC panels depending on the deformation rate. A high contrast ratio can be realized when the transmittance of the scattering state is low.

In this case, the transmittance decreased with increasing the deformation rate below 5%, indicating that the pole direction of the matrix is oriented parallel to the substrate surface and the parallel components of Δn increased. When the matrix deformation became excess at the deformation rate over 5%, the liquid crystal molecules in the matrix are oriented perpendicular to the substrates, and the transmittance increased with increasing the deformation rate.

This phenomenon can be explained as follows. The pole direction of the liquid crystal matrix are three dimensionally random before the compression. After the matrix is compressed in thickness direction, the structure of liquid crystal matrix become anisotropic and the orientation of the liquid crystal matrix becomes randomly in the plane. In the case of this deformation, the pole direction in the matrix is oriented parallel or perpendicular to the substrate surface.

To simplify the explanation, if the matrix structure is supposed to be droplet and liquid crystal molecules are supposed to be aligned parallel to the surface of the polymer wall, the droplets become bi-pole structure and the pole directions are three dimensionally random.

When the deformation rate is small, the pole

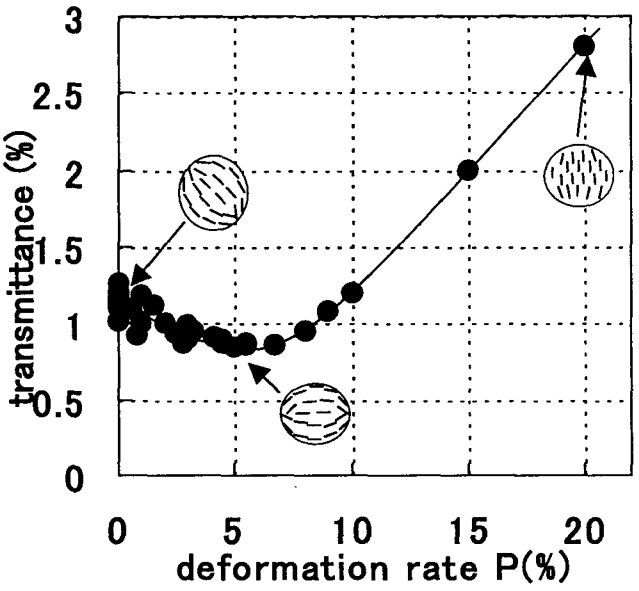

Fig. 4 The transmittance curve of the scattering state as a function of the deformation rate.

direction moves to the horizontal direction, because the rate of the polymer wall parallel to the substrate increases. In this condition, bi-pole structure is kept in the droplet and the molecules of liquid crystal tend to be oriented parallel to the substrate surface, and pole directions are random in the plane, because the matrix structure shows isotropic in the plane.

When the droplet is deformed excessively, the shape of the droplet become a disk-like or cylinder-like, and when the liquid crystal molecules in this disk-like droplet are aligned perpendicular to the substrate, packing energy is minimized. The pole directions are oriented perpendicular to the substrate surface, when the deformation rate is large.

The orientation change may occur in the network structure of the PNLCD as well as in the droplet structure.

Dielectric constants change

This orientation changes were confirmed from measurements of dielectric constants of the panels (ε_{PDLC}). Table 1 shows the dielectric constants and average tilt angle Θ of the liquid crystal in the panels. The average tilt angles Θ are calculated from the dielectric constants using a following equation.

$$\varepsilon_{LC} = \varepsilon_{\perp} + (\varepsilon_{\parallel} - \varepsilon_{\perp})\sin^2\Theta$$

where the ε_{LC} is the dielectric constant of the liquid crystal and ε_{LC} is corrected by following equation because the matrix was made with the mixture of liquid crystal and polymer. V is the containing ratio of the liquid crystal. The dielectric constants for parallel ($\varepsilon_{\parallel}$) and perpendicular component ($\varepsilon_{\perp}$) of liquid crystal and that of the polymer (ε_p) are 3.8, 14.2 and 4.0 in this experiment respectively.

$$\varepsilon_{PDLC} = \left(\frac{1-V^{1/3}}{\varepsilon_p} + \frac{1}{\varepsilon_{LC} V^{1/3} + \varepsilon_p \dfrac{1-V^{2/3}}{V^{1/3}}} \right)^{-1}$$

When the deformation rate was 0%, the average tilt angle was about equal to the value of the three dimensional average (35.2). When the deformation rate was 3%, the dielectric constant became small, indicating that the directions of the liquid crystal molecules moved to the horizontal direction. When the deformation rate was 13%, the dielectric constant became larger and the directions of the liquid crystal molecules changed perpendicular to the substrates.

The deformation rate must be optimized to maximize the contrast ratio, and the optimized deformation rate is considered to depend on the elastic constant of the liquid crystal, the anchoring energy of the polymer-liquid crystal surface, and so on.

Table 1 The dielectric constants and the average tilt angles Θ of the liquid crystal molecules in the panels with increasing the deformation rate P(%).

P(%)	ε_{PDLC}	Θ
0	6.5	37.6
3	5.7	30.5
13	7.0	41.1

Driving voltage

Fig.5 shows driving voltage as a function of the deformation rate, where the driving voltage V90 was measured at the transmittance 90% of the panels. The driving voltage decreased with increasing the deformation rate monotonously.

When the voltage was applied, the direction of the liquid crystal molecule changed perpendicular to the substrate surface, and it is considered that stability of vertically orientation increased depending on the deformation in the structure.

This technique can be developed to increase scattering strength and to decrease the driving voltage at the same time.

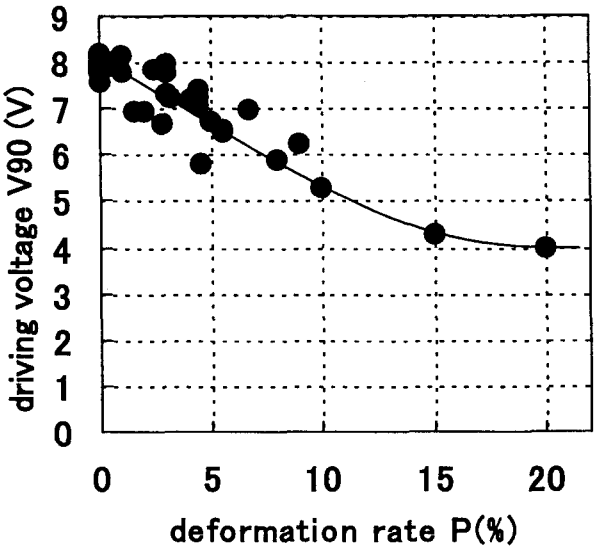

Fig. 5 The driving voltage V90 as a function of the deformation rate.

Influence on alignment changes

Alignment changes from bipole to radial alignment of the liquid crystal molecules in the PDLC panels were reported. [4,5] In this PDLC panels , alignment of liquid crystal molecules to the polymer wall changed from parallel at higher temperature to perpendicular at lower temperature .

Fig.6 shows temperature dependence of the driving voltage V90 and hysteresis of the panels before deformation. The hysteresis was defined by maximum Hys(V), where Hys(V) was defined by a following equation,[5]

Hys(V) = (Tup-Tdown)/Tmax

where Tup and Tdown are the transmittance with increasing voltage from 0V to 10V and decreasing voltage, respectively and Tmax is maximum transmittance.

The driving voltage V90 was found to be 7V at 12℃, and this point was a inflection point. The alignment change occurred at this point. The hysterisis increase rapidly below about this temperature.

Fig.7 shows the driving voltage and hysterisis change at the compressed structure. The temperature where the alignment change occurs increased with increasing the deformation rate of the matrix structure. In this case, the temperature where the alignment change occurs increased from 15 ℃ to 20 ℃. This alignment change caused by the alignment change of liquid crystal molecules on the polymer wall from alignment states parallel to the polymer wall, parallel states, to another states perpendicular to the polymer wall, perpendicular states. It is difficult to consider that the deformation of the matrix changed surface property (parallel states or perpendicular states) of polymer wall. Because of the deformation of the matrix, the liquid crystal molecules are intend to orient perpendicular to the substrate surface, and then the temperature of the alignment change increased. Thus it is concluded that packing energy of liquid crystal molecules in the matrix structure influenced to the alignment of liquid crystal at the polymer wall, although the mechanism of the alignment changes can not be explained completely at present.

The alignment change of the liquid crystal in the PDLC panels might be caused by the structure change of the matrix, because the matrix structure was deformed similar to the compressed state in thickness direction when the volume of the liquid crystal decreases due to the temperature decrease.

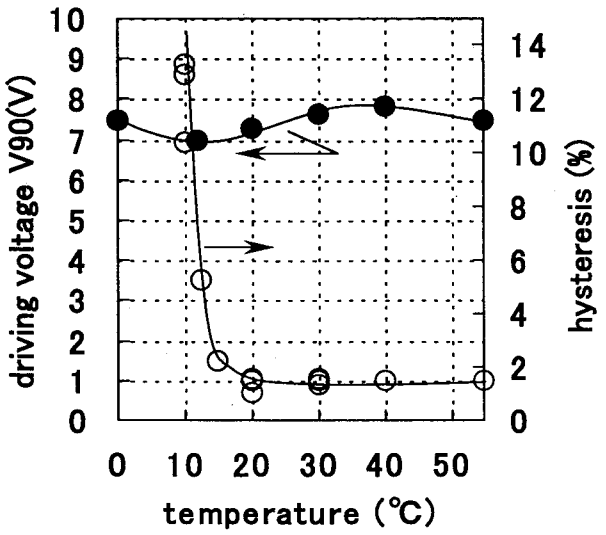

Fig. 6 Temperature dependence of V90 and hysteresis before deformation .

CONCLUSION

We have developed the new technique improving performance of the PDLC panels. This technique increase the contrast ratio of the PDLC panels in practical use. Also we found out that the deformation of the matrix influences the alignment of liquid crystal molecules at the polymer wall. It is important to clarify a mechanism of the liquid crystal alignment in the matrix structure.

A technique which forms this deformation structure uniformly is not established at present. A technique to produce uniformly the PDLC panels may be realized in the near future by improving this technique.

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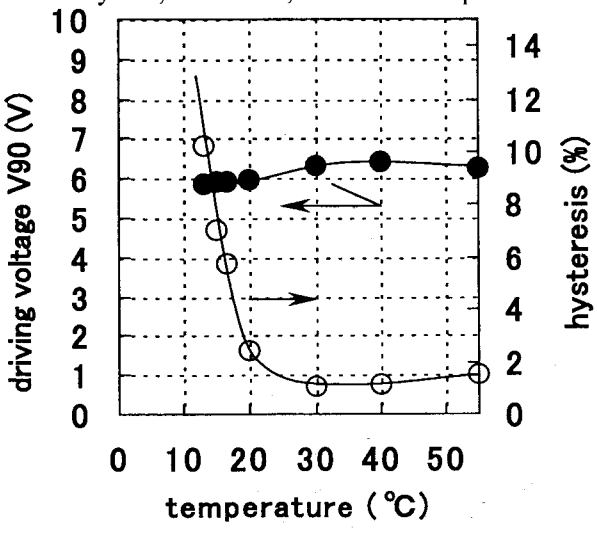

Fig. 7 Temperature dependence of V90 and hysteresis that deformation rate is 5%.